SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN that we, ATSUSHI FUJIOKA, a subject of Japan and residing at Shinjuku-ku, Tokyo, Japan, MASAYUKI ABE a subject of Japan and residing at Shinjuku-ku, Tokyo, Japan and FUMIAKI MIURA, a subject of Japan and residing at Shinjuku-ku, Tokyo, Japan have invented certain new and useful improvements in

"ELECTRONIC VOTING METHOD AND SYSTEM AND
RECORDING MEDIUM HAVING RECORDED THEREON
A PROGRAM FOR IMPLEMENTING THE METHOD"

and we do hereby declare that the following is a full, clear and exact description of the same; reference being had to the accompanying drawings and the numerals of reference marked thereon, which form a part of this specification.

ELECTRONIC VOTING METHOD AND SYSTEM AND RECORDING MEDIUM HAVING RECORDED THEREON A PROGRAM FOR IMPLEMENTING THE METHOD

BACKGROUND OF THE INVENTION

The present invention relates to an electronic voting system and method for implementing secure secret voting in elections, questionnaire surveys or the like which are conducted through a telecommunication system. The invention also pertains to a recording medium having recorded thereon a program for implementing the electronic voting method.

What is intended to mean by the word "voting" herein is a procedure in which voters each choose a predetermined number (one or more) of candidates from those offered to them and a counter counts the number of votes cast for each candidate. The candidates mentioned herein may be not only the names of candidates in elections but also items or headings of choice in statistic surveys. And the content of the vote is identification information representing the candidate chosen by the voter, such as a symbol, name, or heading.

Since the secrete voting scheme provides security for the correspondence between the voters and the contents of their votes and lends itself to protecting the privacy of individuals for their thought and belief, the scheme can be used, for instance, in teleconferencing and questionnaire surveys by CATV or similar two-way communication.

To implement secure secret voting by telecommunication, it is necessary to prevent the impersonation of voters, double voting and a leakage of the content of the vote by wiretapping its message or text. As a solution to these problems, there have been proposed electronic voting schemes using the digital signature technique, for example, in Atsushi Fujioka, Tatsuaki Okamoto and Kazuo Ohta, "A practical secret voting scheme for large scale elections," Advances in Cryptology-AUSCRYPT' 92, Lecture Notes in Computer Science 718, Springer-Verlag, Berlin, pp.244-251 (1993) and Japanese Patent Application Laid-Open No. 19943/94 (laid open November 28, 1994) entitled "Electronic Voting Method and Apparatus."

In this conventional method, a voter V_i encrypts the content of his vote (hereinafter referred to as the vote content) v_i by a key k_i into a ciphertext x_i, then randomizes it by a random number r_i to create a preprocessed text e_i for getting a blind signature, then attaches his signature s_i to the text e_i, and sends the signed text to an election administrator A. The administrator A first verifies the validity of the voter V_i on the basis of the signature s_i, then attaches his blind signature d_i to the preprocessed text e_i, and sends it back to the voter V_i. The voter V_i retrieves a signature y_i of the election administrator A for the ciphertext x_i from the blind signature d_i affixed to the preprocessed text e_i, and sends the administrator's signature y_i to a counter C together with the ciphertext x_i. The counter C makes sure that the ciphertext x_i bears the administrator's signature y_i, and publishes the ciphertext x_i in its entirety. The voter V_i sends the counter C the key k_i used for the encryption of his vote content v_i when his ciphertext x_i is found registered, and if not registered, the voter V_i presents a protest against the counter C. The counter C uses his received key k_i to decode or retrieve the vote content v_i from the ciphertext x_i, and counts the number of votes cast for each candidate.

With this method, however, it is necessary for the voter V_i to confirm the registration of his cipherteXt x_i by checking a list of ballots that is published after completion of the voting of all voters and to send the key k_i to the counter C. Hence, the conventional system lacks usability from a voter's point of view.

Ins a1

~~The followings are pertinent references, but do not solbe the above stated problems: Japanese Patent Application Laid Open Nos. 6-223250 (August. 12, 1994), 6-176228 (June 24, 1994), 7-28915 (Jan. 31, 1995), 10-74182 (March 17, 1998), 10-283420 (Oct. 23, 1998), 1-177164 (July 13, 1989), and 10-74046 (March 17, 1998). D. Chaum, "Elections with Unconditionally-Secret Ballots and Disruption Equivalent to Breaking RSA", in Advances in Cryptology, EUROCRYPT '88, Lecture Notes in Computer Science 330, Springer-Verlag, Berlin, pp. 177-182 (1988), L. F. Cranor et al., "Design and Implementation of a Practical Security-Conscious Electronic Polling System", WUCS-96-02, Department of Computer Science, Washington University, St. Louis (Jan., 1996), M. A. Herschberg, "Secure Electronic Voting Over the World Wide Web", Masters Thesis in Electrical Engineering and Computer Science, Massachusetts Institute of Technology (1997).~~

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a simple and convenient electronic voting system and method which ensure voter privacy in making a complaint about a possible fraud by the administrator, have robustness against system dysfunction and obviate the necessity for voters to send their encryption keys to the counter after voting.

Another object of the present invention is to provide a recording medium on which there is recorded a program for implementing the above electronic voting method.

In the present invention, each voter encrypts his vote content by a public key of the counter, then randomizes the encrypted vote content by a random number to create a preprocessed text, then attaches thereto his signature, and sends the signed text to the election administrator. The election administrator verifies the validity of the voter through utilization of his signature attached to the encrypted text, then attaches a blind signature to the preprocessed text, and sends back the signed preprocessed text to the voter. The voter excludes the influence of the random number from the blind signature attached to the preprocessed text to obtain administrator's signature information about the encrypted vote content, and sends the signature information as vote data to the counter together with the encrypted vote content. The counter publishes the vote data after making sure that the signature information on the encrypted vote content received from the voter bears the administrator's signature. After every voter confirms the registration of his encrypted vote content in the published list of vote data, the counter decrypts the encrypted vote content by a secret key of his own and counts the number of votes cast for each candidate. If his encrypted vote content is not registered in the list of vote content, the voter complains about it to the counter. It is also possible to provide a system configuration wherein a plurality of counters each hold part of a decryption key and all or a certain number of them collaborate to decrypt all the encrypted vote contents.

According to the present invention, the randomization of the vote content with the random number gives no chance for either of the election administrator and the counter to view the vote content, and hence it guarantees the secrecy of voting.

Ins a2

~~The decryption of key is in the possession of the counter, and the voter needs not to communicate with the counter again for vote counting.~~

With the system configuration wherein the plurality of counters work together to decrypt the encrypted vote content, the validity of the voter can be proved simply by sending the encrypted vote and the administrator's signature. That is, even if one or more of the counters commit fraud, the vote content will not be revealed unless all the counters or a certain number of them conspire.

Furthermore, since encrypted vote contents are sent to each of the distributed counters, the intermediate results of the vote count will not be revealed, either, without a conspiracy by all or a certain number of counters--this provides increased fairness in the voting system.

Besides, in the system wherein the encrypted vote contents can by decrypted by only a certain number of counters, even if some of the counters are dishonest or impossible to collaborate in decryption, it is possible to decrypt the vote contents; hence, the system is highly fault tolerant.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram illustrating the general configuration of a voting system according to a first embodiment of the present invention;

Fig. 2A is a table depicting a list of eligible voters;

Fig. 2B is a table depicting a list of voters given the right to vote;

Fig. 2C is a table depicting a list of ballots as received;

Fig. 2D is a table depicting a list of ballots as counted;

Fig. 2E is a table depicting a list of votes polled for each candidate;

Fig. 3 is a block diagram showing an example of the functional configuration of a voter apparatus 100;

Fig. 4 is a block diagram showing an example of the functional configuration of an election-administrator apparatus 200;

Fig. 5 is a block diagram showing an example of the functional configuration of a counter apparatus 300;

Fig. 6 is a diagram depicting a voting procedure;

Fig. 7 is a block diagram illustrating the general configuration of a voting system according to a second embodiment of the present invention;

Fig. 8A is a block diagram depicting an example of the functional configuration of a distributed counter apparatus 300_1 in Fig. 7;

Fig. 8B is a block diagram depicting an example of the functional configuration of each of distributed counter apparatuses 300_2 through 300_U in Fig. 7;

Fig. 9 is a block diagram illustrating the general configuration of a voting system according to a third embodiment of the present invention;

Fig. 10A is a block diagram depicting an example of the functional configuration of each of distributed counter apparatuses 300_1 through 300_{U-1} in Fig. 9; and

Fig. 10B is a block diagram depicting an example of the functional configuration of a distributed counter apparatus 300_U in Fig. 9.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

While the present invention will hereinafter be described as being applied to the voting in elections, the principles of the invention can also be applied intact to the voting in statistic surveys as referred to previously.

EMBODIMENT 1

Fig. 1 schematically illustrates the general configuration of the voting system according to the present invention. Apparatuses 100 of T voters V_i (where i=1,...,T) (which apparatuses 100 will hereinafter be referred to as voter apparatuses) are each connected to an apparatus 200 of an election administrator A (which apparatus 200 will hereinafter be referred to as an administrator apparatus) and a apparatus 300 of a counter C (which apparatus 300 will hereinafter be referred to as a counter apparatus) via nonanonymous and anonymous communication channels 400 and 500, respectively. When sending information to the administrator A via the nonanonymous communication channel 400, the voter V_i adds the information with sender information indicating who the sender is, for example, his name V_i or identification information ID_i. In the case of sending information to the counter C via the anonymous communication channel 500, the voter V_i adds no sender information. The counter C publishes a list of vote contents (a list of votes and a list of the number of votes polled for each candidate), which is accessible from all the voters. Fig. 3 depicts an example of configuration of the voter apparatus 100 in the voting system of Fig. 1, Fig. 4 an example of the configuration of the administrator apparatus 200, Fig. 5 an example of the configuration of the counter apparatus 300, and Fig. 6 an example of a communication sequence in the voting system of the present invention. Fig. 2A exemplifies a list of eligible voters (hereinafter referred to as an eligible-voter list) 240A, Fig. 2B a list of voters authorized to vote (hereinafter referred to as an authorized-voter list) 240B, Fig. 2C a list of ballots as received by the counter C but not yet counted (which list will hereinafter be referred to as a ballot list) 320A, Fig. 2D a list of ballots counted (hereinafter referred to as a counted-ballot list) 320B, and Fig. 2E a list of the numbers of votes polled for individual candidates (hereinafter referred to as a poll list) 320B.

A description will be given of the voting procedure that the voter Vi carries out between he and the counter C after being authorized by the administrator A to vote.

The following is a list of notations that are used in describing the invention below.

$x = \xi_C(v, k_{PC})$: encryption function of the counter C (x: ciphertext, v: vote content, k_{PC}: public key of the counter)

$v = \rho_C(x, k_{SC})$: decryption function of the counter C (k_{SC}: secret key of the counter)

$s = \sigma_i(e)$: signature generating function of the voter V_i (s: signature, e: encrypted vote content)

$e = \zeta_i(s)$: verification function for the signature of the voter V_i

$d = \sigma_A(e)$: a blind signature generating function of the administrator A (d: blind signature)

$z = \zeta_A(y)$: verification function for the signature of the administrator A (y: signature, z: ballot)

$e = \omega_A(z, r)$: randomizing function (r: random number)

$y = \delta_A(d, r)$: derandomizing function (d: blind signature)

The encryption function ξ_C and decryption function ρ_C of the counter C are used in known public key cryptosystems. Now, let it be assumed that the counter C keeps the secret key k_{SC} in secrecy and publishes the public key k_{PC} to the voters. The randomizing function $\omega_A(z, r)$ for the voter V_i to blind the message m by the random number r (to preprocess the ballot for the attachment thereto of the administrator's blind signature) prior to requesting it and the derandomizing function $\delta_A(d, r)$ for removing the random component r from the received blind signature d to extract the signature y of the administrator A attached to the ballot are inevitably determined once the blind signature function σ_A of the administrator A is determined. Such signature functions are, for example, an encryption function and a decryption function of the RSA cryptosystem (Ronald Rivest, Adi Shamir and Leonard Adleman, "A method for obtaining digital signatures and public-ky cryptosystems," Communications of the ACM, Vol. 21, No. 2, pp.120-126 (Feb., 1978)), and the scheme for randomization with a random number as preprocessing for requesting the blind signature is described in detail in David Chaum, "Security without identification: Transaction systems to make big brother obsolete," Communications of the ACM, Vol. 28, No. 10, pp.1030-1044 (Oct., 1985).

Turning next to Fig. 3, the configuration of the voter apparatus

100 will be described. In a storage part 121 there is prestored identification information ID_i of voters and their names V_i. Of the data that is generated in the apparatus 100, data to be used afterward is also stored in the storage part 121. An encryptor 110 encrypts the vote content v_i (the candidate name CND_h in this case) chosen by the voter V_i using the public key k_{PC} of the counter C to obtain the ciphertext $x_i = \xi_C(v_i, k_{PC})$. A tag generator 111 generates a random number t_i, which is revealed only to the voter V_i and is used as a tag in such a manner as described below. A concatenator 112 concatenates the ciphertext x_i with the tag t_i and outputs $z_i = x_i \| t_i$. The output z_i will hereinafter be referred to as a ballot. A random generator 120 generates a random number r_i. A randomizer 130 randomizes the ballot z_i by the random number r_i based on the randomizing function $e_i = \omega_A(z_i, r_i)$ to generate a preprocessed text e_i. A signature generator 140 generates a signature $s_i = \sigma_i(e_i, ID_i)$ that is attached to the preprocessed text e_i to indicate its origin V_i. Data $<e_i, s_i, ID_i>$is sent to the administrator apparatus 200 via the communication channel 400. The voter apparatus 100 is held connected to the administrator apparatus 200 via the communication channel 400 until the former receives a blind signature d_i from the latter.

A derandomizer 150 removes the random component from the blind signature d_i received via a transmitting-receiving part 190 from the administrator apparatus 200 by the random number r_i based on derandomizing function $y_i = \delta_A(d_i, r_i)$, thereby obtaining y_i as the signature of the administrator A for the ballot z_i. A signature verification part 160 verifies the validity of the signature y_i by making a check to see if a verification function $z_i = \zeta_A(y_i)$ holds.

Data $<z_i, y_i>$ is sent as vote data via a transmitting-receiving part 180 to the counter apparatus 300. A list checking part 170 checks the ballot list 320A received via the transmitting-receiving part 180 from the counter apparatus 300 in response to an access thereto from the voter apparatus 100.

The administrator apparatus 200 depicted in Fig. 4 comprises: a storage part 240 for recording therein the eligible-voter list 240A (Fig, 2A) with the identification information ID_i of eligible voters prestored and the authorized-voter list 240B (Fig. 2B) for storing the identification information ID_i of voters authorized to vote; a voter checking part 210 for making a check to see if the identification information ID_i received from the voter is placed on the eligible-voter list; a signature verification part 220 for verifying the validity of the voter's signature s_i attached to the preprocessed text e_i received from the voter by making a check to see if a verification function $e_i = \zeta_i(s_i)$ holds; a voter list generating part 260 for generating the authorized-voter list 240B (Fig. 2B) by writing data on authorized voters in a predetermined area of the storage part 240; a transmitting-receiving part 250 for data exchange with each voter apparatus 100_i; and a signature generator 230 for generating a blind signature $d_i = \sigma_A(e_i)$ to be attached to the preprocessed text e_i.

As shown in Fig. 5, the counter apparatus 300 comprises: a signature verification part 310 for verifying the validity of the signature y_i of the administrator A by making a check to see if $z_i = \zeta_A(y_i)$ holds for the ballot z_i and the administrator signature y_i in the vote data $<z_i, y_i>$ received via a receiving part 360 from the voter apparatus 100, through the use of a verification function $\zeta_A(y_i)$; a storage part 320 which gives a serial number q_i to the vote data $<z_i, y_i>$and places and stores it on the list of ballots (hereinafter referred to as a ballot list) 230A (Fig. 2C); a separation part 350 for separating the ciphertext x_i from the ballot $z_i = x_i \| t_i$; a decryptor 330 for decrypting the ciphertext x_i by the counter's secret key k_{sc} based on the decryption function ρ_C to obtain $v_i = \rho_C(x_i, k_{SC})$ as the vote content; and a counter 340 for counting the vote content v_i. Further, the vote data corresponding to the serial number q of the ballot list 320A held in the storage part 320 is added with the decrypted vote content v_i as depicted in Fig. 2D. The results of the vote count, that is, the numbers of votes polled for each candidate (CND_h, where h = 1, 2, ...), are stored as the poll list 320B of Fig. 2E in the storage part 320. The contents of the ballot list 320A and the counted-ballot list 320B are sent via a transmitting-receiving part 380 to the voter apparatus 100 that has accessed the counter apparatus 300.

Turning next to Fig. 6, the voting procedure in the first embodiment will be described.

Step 1: The voter V_i makes preparations for voting by the voter apparatus 100 (Fig. 3) as described below.

Step 1-1: The voter V_i encrypts the vote content v_i by the encryptor 110 using the public key k_{PC} of the counter C and the encryption function ξ_C to generate the ciphertext

$$x_i = \xi_C(v_i, k_{PC}).$$

Then, the voter V_i generates the tag t_i by the tag generator 111 and concatenates it with the ciphertext x_i by the concatenator 112 to obtain the ballot

$$z_i = x_i \| t_i.$$

The tag t_i is, for instance, a random number and only the voter V_i

knows that it is his own tag.

Step 1-2: The voter V_i generates the random number r_i by the random generator 120, and randomizes the ballot z_i by the randomizer 130 using the random number r_i to create the preprocessed text

$$e_i = \omega_A(z_i, r_i).$$

Step 1-3: The voter V_i generates, by the signature generator 140, the signature s_i for the preprocessed text e_i and the identification information ID_i:

$$s_i = \sigma_i(e_i, ID_i).$$

After this, the voter V_i sends the data $<e_i, s_i, ID_i>$ to the administrator apparatus 200.

Step 2: The administrator apparatus 200 (Fig. 4) has prestored therein the relationship between the registered eligible voters' names V_i and their identification information ID_i as the eligible-voter list 240A (Fig. 2A), and has the authorized-voter list 240B (Fig. 2B) in which the names V_i or identification information ID_i of the voters authorized to vote are written by the voter list generating part 260. Since the authorized-voter list is published after the voting of all voters, the names V_i or identification information ID_i of the authorized voters are recorded, depending on whether they agree or disagree to reveal their names to the public. This is predetermined prior to the start of the actual voting. The following description will be given on the assumption that the identification information ID_i of the voters V_i is written in the authorized-voter list 240 B (Fig. 2B). At the start of the voting procedure there is nothing recorded in the voter list. The administrator A performs by his apparatus 200 the following procedure to give the eligible voters the right to vote.

Step 2-1: The administrator A makes sure that the voter is eligible, by making a check in the voter checking part 210 to see if his identification information ID_i is contained in the eligible-voter list 240A (Fig. 2A). If not, the administrator A rejects the authorization of the voter V_i.

Step 2-2: The administrator A ascertains whether the voter V_i has been authorized to vote, by making a check in the voter checking part 210 to see if his identification information ID_i has already been written in the authorized-voter list 240B (Fig. 2B). If the identification information ID_i is found in the authorized-voter list 240B, the administrator A regards the voting by the voter V_i as double voting and rejects the authorization.

Step 2-3: If the identification information ID_i is not found in the authorized-voter list 240B, then the administrator A makes a check to determine in the signature verification part 220 whether s_i, e_i and ID_i satisfy the following equation:

$$(e_i, ID_i) = \zeta_i(s_i).$$

If so, the administrator A provides e_i to the signature generator 230 to calculate the signature d_i:

$$d_i = \sigma_A(e_i).$$

Then the administrator A sends the signature d_i via the transmitting-receiving part 250 to the voter apparatus 100 and, at the same time, adds the identification information ID_i of the voter V_i by the voter list generating part 260 to the authorized-voter list 240B (Fig. 2B) in the storage part 240.

Step 2-4: After all voters vote, the administrator A publishes the authorized-voter list 240B and the number of voters who actually voted. For this publication, the administrator A preinforms all the eligible voters that they are allowed to access the authorized-voter list 240B in the storage part 240 of the administrator apparatus 200 via an arbitrary communication channel within a certain period beginning on a predetermined date and time. The access to the authorized-voter list 240B can be made, for example, using a predetermined telephone number. The list 240B may also be published at a predetermined address on the Internet.

Step 3: The voter V_i generates the ballot and its signature information by the voter apparatus 100 (Fig. 1) as described below.

Step 3-1: The voter V_i inputs d_i and r_i into the derandomizer 150 to obtain the following signature information y_i on the ballot z_i:

$$y_i = \delta_A(d_i, r_i).$$

Step 3-2: The voter V_i makes sure that y_i is the signature of the administrator A, by making a check in the signature verification part 160 to see if the following equation holds:

$$z_i = \zeta_A(y_i).$$

If not, the voter V_i points out fraud by the administrator A, presenting the data $<e_i, d_i>$.

Step 3-3: If it is verified that the signature is valid, the voter V_i sends data $<z_i, y_i>$via the transmitting part 180 to the counter apparatus 300 over the anonymous communication channel 500.

Step 4: The counter C collects ballots by the counter apparatus 300 (Fig. 5) as described below.

Step 4-1: The counter C receives the vote data $<z_i, y_i>$from the voter via the receiving part 360, and makes sure that y_i is a valid signature on the ballot z_i, by making a check in the signature verification part 310 to see if the following equation holds:

$z_i = \zeta_A(y_i)$.

If the equation holds, the counter C gives the ballot z_i and its signature y_i a serial number common q thereto and places them as vote data <q, z_i, y_i) on the ballot list 230A (Fig. 2C) by a vote list generating part 370.

Step 4-2: After all voters vote, the counter C publishes the ballot list 320A by allowing an access to the storage part 320 via the transmitting-receiving part 380. This list is supposed to be accessible from all the voters. As is the case with the authorized-voter list 240B, the counter C preannounces the period and place for publishing the ballot list 320A.

Step 5: The voter V_i conducts the following verification by the voter apparatus 100.

Step 5-1: The voter V_i accesses the storage part 320 of the counter apparatus 300 via the transmitting-receiving part 180, then receives the contents of the ballot list 320A, and makes a check in the list checking part 170 to see if the number of ballots placed on the ballot list 320A is equal to the number of voters published in step 2-4. If not, the voter V_i publishes the serial number q and the random number r_i to point out fraud by the administrator A.

Step 5-2: The voter V_i makes a check in the list checking part 170 to see if his ballot z_i is contained in the ballot list 320A. This can be done by verifying whether the ballot z_i itself is contained in the list 320A, or whether the tag t_i in $z_i = x_i \| t_i$ is his tag. If the ballot z_i is not found on the list 600, then the voter V_i points out fraud of the counter C, presenting the vote data <z_i, y_i>.

Step 6: The counter C performs the following vote counting by the counter apparatus 300.

Step 6-1: When no allegation of fraud is received via the receiving part 360 from the voter V_i within a predetermined period of time after the reception of his ballot z_i and signature y_i, the counter C separates the ciphertext x_i from the ballot $z_i = x_i \| y_i$ in the separation part 350, and decrypts it by the decryptor 330 using the secret key k_{SC} to detect the vote content v_i:

$$v_i = \rho_C(x_i, k_{SC}).$$

Then the counter C verifies whether the vote content v_i is valid or not, that is, whether it correctly represents the name or symbol of any one of the candidates offered in advance. If not so, the vote is regarded as invalid.

Step 6-2: The counter C counts the vote contents v_i in the ballot list 320A of Fig. 2C by means of the counter 340 to obtain the number of votes polled for each candidate, then publishes the results of the vote count as the poll list 320B of Fig. 2E and, at the same time, adds v_i to a q-th piece of data $<x_i, t_i, y_i)$ as depicted in Fig. 2D. The results of the vote count are published together with the ballot list 320A.

Step 7: The voter V_i verifies the validity of the manipulation or management of the counter C by means of the voter apparatus 100. That is, the voter V_i checks whether all vote contents v_i have been contained in the ballot list 320A of Fig. 2C, and whether the ciphertext x_i and the vote content v_i of the voter V_i correspond to each other.

Incidentally, Step 5 may be omitted, and the publication of the poll list 320B in Step 6-2 and Step 7 may also be omitted.

In this embodiment, since the voter V_i encrypts the vote content v_i into $x_i = \xi_C(v_i, k_{PC})$ by the encryption function ξ_C of the counter C and sends him the vote data $<z_i, y_i>$, the counter C could view the vote content v_i by decrypting the ciphertext x_i in the ballot z_i with the decryption function $v_i = \rho_C(x_i, k_{SC})$ through the use of the secret key k_{PC} of the counter C even before the publication of the ballot list 320A in step S4-2. In other words, the counter C is in a position to get information such as the trend of voting or intermediate results of the vote count prior to the publication of the ballot list 320B and hence leak the information to a particular person prior to the publication of the official results of the vote count--this is undesirable in terms of the fairness of elections. Besides, according to the first embodiment of the invention, if the counter apparatus 300 suffers a breakdown, the vote count cannot be completed on schedule in some cases. A description will be given below of another embodiment of the present invention which is intended to obviate these problems by the participation of plural distributed counters in the decryption and vote counting processes.

The distributed counters use the same crypto-functions (the encryption function ξ_C and the decryption function ρ_C) as in the public-key cryptosystem. However, the decryption process involves the use of a distributed secret key k_{SCj} of every distributed counter, or requires a certain number (a threshold value U_t (where $2 <U_t <U$) of people to work together. The crypto-functions mentioned above are encryption and decryption functions of, for instance, the ElGamal cryptosystem (Taher ElGamal, "A public key cryptosystem and a signature scheme based on discrete logarithms," IEEE Transactions on Information Theory, Vol. IT-31, No. 4, pp.469-472 (July, 1985)). The scheme of decryption by the distributed counters using such crypto-functions and the scheme using the threshold value are described in detail in Yvo Desmedt and Yale Frankel, "Threshold cryptosystems," in Advances in Cryptology-CRYPTO'89, Lecture Notes in Computer

Science 435, Springer-Verlag, Berlin, pp.307-315 (1990).

EMBODIMENT 2

Fig. 7 schematically illustrates the general configuration of a voting system according to a second embodiment of the present invention. This embodiment is identical with the first embodiment in that every voter apparatus 100 is connected to the administrator apparatus 200 through the communication channel 400 and to one counter apparatus through the anonymous communication channel 500, but structurally differs in that a plurality of counter apparatuses (hereinafter referred to as distributed counter apparatuses) 300_j (where j = 1, ..., U). The distributed counter apparatus 300_1 decrypts ciphertexts x_i from all voters to generate x_{i1} and sends it to the next distributed counter 300_2; similarly, a j-th distributed counter apparatus 300_j decrypts decrypted data x_{ij-1} received from the immediately preceding distributed counter apparatus 300_{j-1} to generate decrypted data x_{ij} and sends it to the next distributed counter apparatus 300_{j+1}. The vote content v_i is obtained for the first time with the decryption process by the last distributed counter apparatus 300_U. As is the case with the first embodiment, the identification information ID_i of the voter V_i is attached to the data that is sent from the voter apparatus 100_i to the administrator 200 via the communication channel, but no identification information ID_i accompany the data that is sent to the distributed counter apparatus 300_1 via the anonymous communication channel 500.

This embodiment is identical with the first embodiment in the communication sequence, the configuration of each voter apparatus 100 and the configuration of the administrator apparatus 200 except that the counter apparatus 300 is substituted with a plurality of distributed counter apparatuses. Furthermore, this embodiment is common to the first embodiment in that each voter encrypts the vote content v_i by $x_i = C(v_i, k_{PC})$ through the use of the common public key k_{PC}. The counters C_1 to C_U each have one of U partial secret keys k_{SC1}, k_{SC2}, ..., k_{SCU} into which the secret key k_{SC} is split, and perform the decryption process using them, respectively, but no distributed counter apparatus 300j can decrypt the vote content v_i from the ciphertext x_i on a stand-alone basis. In the case of employing the aforementioned ElGamal cryptosystem, the partial secret keys k_{SC1}, k_{SC2}, ..., k_{SCU} can be set such that the sum total of their values equals the value of the secret key k_{SC} corresponding to the public key k_{PC}. This is described in the aforementioned Desmedt-Frankel literature.

Fig. 8A depicts the configuration of the first distributed counter apparatus 300_1 that collects ballots from the voter apparatuses 100_1 to 100_T. The distributed counter apparatus 300_1 comprises a signature verification part 310, a storage part 320, a counter 340, an separation part 340, a partial decryption part 331, a receiving part 360, a vote list generating part 370, and a transmitting-receiving part 380. The first distributed counter apparatus 300_1 differs from the counter apparatus 300 in the first embodiment of Fig. 5 in the point described below. First, the partial decryption part 331 generates decrypted intermediate data x_{i1} by performing a description process $x_{i1} = \rho_{C1}(x_i, k_{SC1})$ on the ciphertext x_i through the use of the partial secret key k_{SC1}, the decrypted intermediate data x_{i1} being sent to the next distributed counter apparatus 300_2. Second, the counter 340 receives the decrypted vote content v_i from the last distributed counter apparatus 300_U and counts the votes. The second through

U-th distributed counter apparatuses 300_2 to 300_U are common in that they have only a partial decryption part 331 as shown in Fig. 8B, in which the j-th distributed counter apparatus (where $2 \leq j \leq U$) is exemplified. The j-th distributed counter apparatus 300_j performs a decryption process $\rho_{Cj}(x_{ij-1}, k_{SCj})$ of decrypted intermediate data x_{ij-1} from the preceding-stage distributed counter apparatus 300_{j-1} to generate decrypted intermediate data x_{ij} and sends it to the next-stage distributed counter apparatus 300_{j+1}. The distributed counter apparatus 300_U of the last stage obtains the ultimate decrypted result x_{iU} as the vote content $x_i = x_{iU}$ by a decryption process $x_{iU} = \rho_{CU}(x_{iU-1}, k_{SCU})$, and sends the vote content v_i to the first distributed counter apparatus 300_1.

A description will be given of the voting procedure in the second embodiment. This embodiment is common to the first embodiment in the procedure from Steps 1 through 5. However, it is the first distributed counter apparatus 300_1 that receives the vote data $<z_i, y_i>$ from each voter apparatus 100_i. The second embodiment modifies Steps 6 and 7 in the first embodiment as described below, and U represents the number of distributed counter apparatuses.

Step 6: The distributed counter C_j (where j = 1, ..., U) performs the vote counting process by the distributed counter apparatus 300_j as described below.

Step 6-1: The first distributed counter apparatus 300_1 separates $z_i = x_i \| t_i$ in the vote data $<z_i, y_i>$from each voter apparatus 100_i (where i = 1, ..., T) by the separation part 350 into the ciphertext x_i and the tag y_i, and performs the following decryption process in the partial decryption part 330 using the partial secret key k_{SC1} to obtain the decrypted intermediate data x_{i1}:

$x_{i1} = \rho_{C1}(x_i, k_{SC1})$.

Then the distributed counter apparatus 300_1 sends the decrypted intermediate data x_{i1} to the second distributed counter apparatus 3002.

Thereafter, the j-th distributed counter apparatus 300_j similarly performs the following decryption process of decrypted intermediate data x_{ij-1} from the (j-1)th distributed counter apparatus 300_{j-1} in the partial decryption part 330 using the partial secret key k_{SCj}:

$x_{ij} = \rho_{Sj}(xi, k_{SCj-1})$,

and sends the data x_{i1} to the next (j+1)th distributed counter apparatus 300_{j+1}.

The last U-th distributed counter apparatus 300_U obtains the vote content v_i by performing the following description process of decrypted intermediate data x_{iU-1} from the (U-1)th distributed counter apparatus 300_{U-1} in the partial decryption part 330 using the partial secret key k_{SCU}:

$v_i = x_{iU} = \rho_{CU}(x_i, k_{SCU})$.

The U-th distributed counter apparatus 300U makes a check to see if the thus obtained vote content v_i is valid.

Step 6-2: The U-th distributed counter C_U counts the vote contents v_i by the counter 340, then publishes the results of the vote count and, at the same time, adds the vote contents v_i to the poll list 320B.

Step 7: The voter V_i verifies the validity of the manipulation or management of the U-th distributed counter apparatus 300_U C by means of the voter apparatus 100_i.

As described above, according to the second embodiment, the plurality of distributed counter apparatuses 300_1 to 300_U sequentially perform the decryption process and the distributed counter apparatus 300_U ultimately obtains the vote content v_i; hence, no distributed counter is allowed to view the vote content v_i singly prior to the vote counting.

THIRD EMBODIMENT

Fig. 9 illustrates the general configuration of a voting system according to a third embodiment of the present invention. In this embodiment each voter apparatus 100_i (where i = 1, ..., T) is made connectable to all the distributed counter apparatuses 300_1 to 300_U through the communication channels 500, and sends its generated vote data $<z_i, y_i>$ to all of the distributed counter apparatuses 300_1 to 300_U. The configurations of each voter apparatus 100i and the administrator apparatus 200 are the same as in the first and second embodiments.

The first to (U-1)th distributed counter apparatuses 300_1 to 300_{U-1} are all identical in configuration. Fig. 10A depicts the configuration of the j-th distributed counter apparatus 300_j, which comprises: a signature verification part 310 for verifying the validity of the signature y_i for the ballot z_i in the vote data $<z_i, y_i>$ received from each voter apparatus 300_i; a separation part 350 for separating the ciphertext x_i from the ballot z_i; and a partial decryption part 331 for performing the description process $x_{ij} = \rho_{Cj}(x_i, k_{SCj})$ of the ciphertext x_i by the partial secret key k_{SCj} to obtain the decrypted intermediate data x_{ij}, which is sent to a predetermined one of the distributed counter apparatuses, in this example, 300_U. As depicted in Fig. 10B, the distributed counter apparatus 300U additionally comprises, in the configuration of Fig. 10A, a storage part 320, a total decryption part 332, a counter 340, a vote list generating part 370 which gives a serial number q to each of the vote data $<z_i, y_i>$received from all of the distributed counter apparatuses $300_1, ..., 300_U$ and writes it in the ballot list 320A, and a transmitting-receiving part 380 which allows the voter apparatuses to access the ballot list 320A and the poll list 320B. In the storage part 320 there are made up a ballot vote list 320A on which to place vote data received from the other distributed counters 300_1 to 300_{U-1} and a poll list 320B on which to place the total number of ballots polled for each candidate. The total decryption part 332 performs the decryption process $v_i = \rho_C(x_{i1}, ..., X_{iU})$, using the decryption function ρ_C, for the decrypted intermediate data x_{i1} to x_{iU} generated in the respective distributed counter apparatuses 300_1 to 300_U to obtain the vote content v_i, and provides it to the counter 340. The counter 340 verifies the validity of the vote content v_i and, if valid, adds 1 to the number of ballots polled for the corresponding candidate in the poll list 320B in the storage part 320. At the same time, the counter 340 adds v_i to the corresponding vote data on the ballot list.

This embodiment also inhibits any of the distributed counter apparatuses from decrypting the vote content v_i from the ciphertext x_i on a stand-alone basis, and hence it ensures fraud-free, fair elections.

MODIFICATION 1

In the second and third embodiments the vote content v_i cannot be decrypted from the ciphertext x_i without collaboration of all the distributed counters C_1 to C_U. This embodiment modifies the above-described decryption process by requiring at least L (where $2 \leq L \leq U-$

1) distributed counter apparatuses to work together to decrypt the vote content v_i from the ciphertext x_i, using the public key k_C. This can be done, for example, by the application of the aforementioned Desmedt-Frankel scheme to the configuration of the partial decryption part 331. This method will be described below as being applied to the second embodiment (Figs. 7, 8A and 8B).

For example, when any one 300_j of the distributed counter apparatuses 300_2 through 300_U suffers a breakdown, the distributed counter apparatus 300_{j-1} sends the decrypted intermediate data x_{ij-1} to the distributed counter apparatus 300_{j+1}, bypassing the failing one 300_j. The distributed counter apparatus 300_{j+1} decrypts the received decrypted intermediate data x_{ij-1} by performing the decryption process $x_{ij+1} = \rho_C(x_i, k_{SCj+1})$ with the partial secret key k_{SCj+1} to obtain the decrypted intermediate data x_{ij+1}, and passes it to the next distributed counter apparatus 300_{j+2}. The method for generating the secret key for use in this case is described, for example, in the aforementioned Desmedt-Frankel literature. Assume that all the distributed counter apparatuses 300_1 through 300_U have the configuration depicted in Fig. 8A. In this instance, even if the first distributed counter apparatus 300_1 breaks down, the distributed counter apparatus 300_2 of the next stage substitutes therefor to receive the vote data $<z_i, y_i>$from the voter apparatuses 100_1 to 100_T. The distributed counter apparatus 300_U of the final stage sends the decrypted vote content v_i to the distributed counter apparatus 300_2 that carries out the required operation in behalf of the failing distributed counter apparatus 300_1. Thus this embodiment enables the vote counting to carried out regardless of which distributed counter apparatus breaks down.

MODIFICATION 2

With the application of the Desmedt-Frankel scheme to the partial decryption part 331 and the total decryption part 332, it is also possible, in the third embodiment (Figs. 9, 10A and 10B), to decrypt the vote content v_i if the decrypted intermediate data by at least L (where $2 \leq L \leq U-1$) distributed counter apparatuses is obtainable. For example, when the distributed counter apparatuses 300_1 through 300_{U-L} break down, decrypted intermediate data x_{iU-L+1} to x_{iU} from the remaining distributed counter apparatuses 300_{U-L+1} to 300_U are provided to the total decryption part 332 of the distributed counter apparatus 300_U for the decryption of the vote content v_i through the decryption process $v_i = \rho_C(x_{iU-L+1}, X_{iU-L+2}, ..., x_{iU})$ of the received pieces of decrypted intermediate data. The counter 340 verifies the validity of the thus decrypted vote content v_i and, if valid, adds 1 to the number of polls voted for the candidate corresponding to v_i on the poll list 320B in the storage part 320.

With the application of the configuration of Fig. 10B to all of the distributed counter apparatuses 300_1 to 300_U in this modification, even if a total of U-L distributed counter apparatuses break down, it is possible to count the votes by causing one of the remaining distributed counter apparatuses to perform the same operation as described previously with reference to Fig. 10B.

Figs. 3 to 5, 8A, 8B, 10A and 10B depict the functional configurations of the respective apparatuses; their functions each can be implemented into operation by means of a controller, or they can be executed wholly or partly by a computer.

EFFECT OF THE INVENTION

As described above, the present invention encrypts the vote content v_i with the public encryption key k_{PC} of the counter, and hence it obviates the necessity for the voter to send a key to the counter for the decryption of the vote content v_i.

With plural counters, the vote counting cannot be started without the consent of them all.

In the case where a fixed number of counters can count the votes, it is possible to perform the vote counting by the collaboration of a certain number of valid or normal counter apparatuses, protecting the vote counting from the influence of fraud or failing apparatus.

Moreover, an alteration of the vote content by the counter could be detected by checking the published list of vote contents. That is, when having found that his vote has not been counted, the voter needs only to point out or allege fraud by publishing the encrypted ballot x_i and the administrator's signature y_i. In this instance, when the number of dishonest counters is fixed, the voter privacy is protected.

Besides, according to the present invention, since the vote content is sent after being encrypted with the encryption key, it is possible to prevent a fraud that, at the time of collecting ballots, one of the plural counters leaks the intermediate result of vote count to affect the election.

As will be appreciated from the above, the present invention provides increased convenience to voters through utilization of the counter's encryption key and, by using plural counters, protects against the fraud or leaking the intermediate result of the vote count to affect the election.

It will be apparent that many modifications and variations may be effected without departing from the scope of the novel concepts of the present invention.